Nanomaterial-amplified chemiluminescence systems and their applications in bioassays

Qianqian Li, Lijuan Zhang, Jinge Li, Chao Lu

Nanomaterial-amplified chemiluminescence (CL) has become a growing area of interest in recent years. We review the development of nanomaterial-amplified CL systems and their applications in bioassays. We mainly focus on nanoparticles (gold, platinum, silver, bimetallic, semiconductor and magnetic). Furthermore, we discuss some critical challenges in this field and possible solutions to overcome these challenges.

Keywords: Bimetallic nanoparticle; Bioassay; Chemiluminescence; Gold nanoparticle; Magnetic nanoparticle; Nanomaterial; Nanoparticle; Platinum nanoparticle; Semiconductor nanoparticle; Silver nanoparticle

Qianqian Li, Lijuan Zhang, Jinge Li, Chao Lu*
State Key Laboratory of Chemical Resource Engineering, Beijing University of Chemical Technology, Beijing 100029, China

*Corresponding author.
Tel./Fax: +86 10 64411832;
E-mail: luchao@mail.buct.edu.cn

1. Introduction

Nanometer (nm)-sized particles (NPs) have attracted a great deal of attention due to their fascinating properties and potential applications in nanotechnology and biotechnology. NPs show distinct physical and chemical properties that are characteristic of neither atoms nor bulk counterparts [1–3]. NPs have quantum size effects, high surface energy and the large surface area, which dramatically changes their density states and the spatial scale of their electronic motion. NPs therefore have strongly catalytic properties for redox reactions, which are determined by their size distribution, shapes and stabilizing agents, and are promising for signal amplification [4–7].

For over 30 years, chemiluminescence (CL) has been an attractive topic of intensive research in view of its fundamental significance and the diversity of practical applications [8–12]. CL is based on the production of electromagnetic radiation observed when a chemical reaction yields an electronically-excited intermediate, which either luminesces (direct CL) or donates its energy to another molecule responsible for the emission (indirect or sensitized CL). In contrast to the other optical techniques (e.g., spectrophotometry and fluorescence), the attractiveness of the CL technique lies in the absence of unwanted strong background light, low noise signals, better sensitivity and wide linear dynamic range. Moreover, because there is no excitation source and no optical filters, apparatus is simple, robust, cost effective, and suitable for automation. As a powerful analytical tool, CL detection is therefore widely applied in many analytical fields (e.g., environmental, pharmaceutical and food analysis) [13–16].

In the past two decades, liquid-phase CL has grown into a well-established method in analytical chemistry. However, the study of liquid-phase CL was mostly based on molecular and ion systems, which have low quantum yield, and its applications in analysis are limited [17–19]. In recent years, the study of CL was extended to NP systems from traditional molecular systems in order to improve the sensitivity and the stability, mainly resulting from the large surface area and special structure of nanomaterials [20]. In these systems, metal NPs can participate in CL reactions as catalyst, reductant, luminophor or energy acceptor.

In this article, we review the development in nanomaterial-amplified CL and cite applications in bioanalytical fields published in recent years. We highlight CL systems involving different kinds of NP,

0165-9936/$ - see front matter © 2011 Elsevier Ltd. All rights reserved. doi:10.1016/j.trac.2010.11.008

Table 1. The chemiluminescence (CL) systems amplified by different metal nanoparticles

Metal nanoparticles	CL systems	Ref.
Gold nanoparticles		
	Luminol-H_2O_2	[27,36–40]
	Luminol-$Fe(CN)_6^{3-}$	[41]
	Luminol-IO_4^-	[42–45]
	Luminol-$AgNO_3$	[46,47]
	TCPO-H_2O_2	[48,49]
	KIO_4-NaOH-Na_2CO_3	[50]
	$KMnO_4$-H_2SO_4	[51]
	HCO_4^--eosin Y	[52]
	Ce(IV)-Na_2SO_3	[53]
Platinum nanoparticles		
	Luminol-H_2O_2	[55,57]
	Lucigenin-NaOH-H_2O_2	[56]
Silver nanoparticles		
	Tris(2,2'-bipyridyl)ruthenium(II)-Ce(IV)	[58]
	Luminol-H_2O_2	[59–61]
	Lucigenin-NaOH	[62]
Bimetallic nanoparticles		
Au-Ag	Rhodamine 6G-Ce(IV)	[65]
Pd–Ag	Luminol	[66]
Semiconductor nanoparticles		
	H_2O_2	[73,75,77,79]
	Luminol-$KMnO_4$	[74]
	$KMnO_4$	[75]
	Tween20-H_2O_2	[76]
	H_2O_2-HCO_3^-	[78]
	$K_3Fe(CN)_6$	[80]
	Luminol-H_2O_2-horseradish peroxidase	[81]
	Luminol-H_2O_2	[82,87]
	Ce(IV)-SO_3^{2-}	[83]
	$NaIO_4$-H_2O_2	[84]
	Ethanol	[85,86]
Magnetic nanoparticles		
	Luminol-H_2O_2	[91,92,94,95]
	Luminol-H_2O_2-Fe^{2+}	[93]
	H_2S	[96]

including gold (AuNPs), platinum (PtNPs), silver (AgNPs), bimetallic NPs, semiconductor NPs and magnetic (MNPs) (Table 1). Finally, we also offer some perspectives on the potential for NPs to be really applied more extensively in analytical fields.

2. Gold nanoparticles

AuNPs are among the most widely used nanomaterials in the recent decades, and have been applied to absorption spectroscopy, fluorescence spectroscopy, Raman spectroscopy, electrochemistry, and electron microscopy [21–24]. The catalysis of AuNPs for liquid-phase redox reactions is an interesting topic [25,26]. In 2005, AuNP-amplified luminol CL was first reported by Cui [27]. Since then, investigation of different CL systems based on AuNPs has been carried out extensively [e.g., systems using luminol-H_2O_2, periodate (IO_4^-)-NaOH-Na_2CO_3, potassium permanganate ($KMnO_4$)-H_2SO_4, bis(2,4,6-trichlorophenyl) oxalate (TCPO)-H_2O_2, peroxymonocarbonate (HCO_4^-)-eosin Y and Ce(IV)-Na_2SO_3].

Here, we review AuNP-amplified CL by system.

2.1. Gold-nanoparticle-amplified luminol CL system

Since the CL phenomenon of luminol was first reported by Albrecht in 1928 [28], luminol has become the most frequently used CL reagent. The CL reaction comprises oxidation of luminol, in alkaline conditions in the presence of catalyst or co-oxidant, to produce the 3-aminophthalate ion in the excited state, which emits blue light at 425 nm on returning to the ground state [29–31]. The luminol-H_2O_2 CL reaction is one of the most popular CL reactions and plays an important role in modern chemical analysis [32–35]. AuNPs as catalysts for the luminol-H_2O_2 CL system were first reported by Cui [27] in 2005, and the luminophors of this CL system were the